OPERATIONAL COSTS OF APPLYING DAILY COVER MATERIAL AT SANITARY LANDFILLS IN NORTH CAROLINA

Prepared to fulfill the
Requirements of

CE 598, Master's of Civil Engineering Research Project

for
Dr. Richard R. Rust, Chairman
Dr. Charles K. Coe
Dr. J.W. Horn

by
Greg Emanuel

14 January 1988

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1. INTRODUCTION

Daily operations at sanitary landfills constitute a significant expense for the many local governmental units that own and operate them. Several trends effect this expense, and all are contributing to escalating landfill costs.

The first trend is toward more stringent regulatory requirements for the permitting and design of new landfills. With new liner and monitoring requirements and increased public resistance to new sites, the costs of opening new landfills are becoming prohibitive for many local governments.

The second trend is a result of the first. To avoid opening a new landfill, operators are doing all they can to extend the life of existing landfills. Wide-spread use of volume-reduction techniques such as compaction and incineration are evidence of this trend. Unfortunately, one very important aspect of daily landfill operations is often overlooked when concentrating on volume-reduction techniques, that of the daily cover.

Having sufficient daily cover for the entire volume capacity of the landfill is crucial; because without it, previously successful efforts at volume reduction become meaningless. Daily cover, not available volume, can limit the landfill's life, and volume-reduction efforts are wasted.

The shortage of available daily cover material is a reality at an increasing number of landfills. Unfortunately, many operators aren't aware of the shortage until it is too late. The shortage can result from poor soil-volume planning,

excessive use of soil early in the landfill's life, or changed volume plans. Whatever the reason, many landfills are being closed due to a shortage of economical cover material. Some operators have chosen to haul cover material from great distances, or purchase adjacent land simply for use as a borrow pit. Eventually, the cost of purchasing and hauling soil daily cover forces the closure of many landfills long before their useful volume capacity is reached.

2. PROBLEM STATEMENT

The problem is to find a substitute for soil daily cover that is reliable, cost-effective, and meets the criteria of daily cover: vector, odor, fire, wind, and erosion control; trafficability; and in some cases, aesthetics.

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3. PURPOSE OF STUDY

This study is intended to aid landfill operators and local governments in making economic decisions about daily cover. The accepted solution for daily cover is the use of soil; the EPA requires a 6" minimum of soil for daily cover. This report challenges the soil cover solution by looking at an alternative daily cover material and technique. the use of geotextile fabrics.

Narrowly stated, the goal of this research is to identify and quantify the advantages and disadvantages of using fabric as a replacement for soil daily cover. For economic comparisons, **both** conventional operations and the use of geotextiles are studied. Specifically, the focus is on the **operational** installed costs of daily cover. To insure that the research can be applied to most landfills, the research uses various cover materials, different site conditions, and different installation techniques. These variables will likely affect daily cover costs, so an effort is made to locate the key variables. While the best solution for each site will be determined by its unique characteristics, this study attempts to provide a general method for conducting economic comparisons of alternatives.

4. METHODS OF DATA COLLECTION

A. Time-Lapse Photography

Time-lapse photography is a useful technique for examining repetitive operations like those found on a landfill. The technique exposes movie film at very slow intervals to gather a large amount of information on one reel. After filming, a large time block can be quickly analyzed for cycle times and hence productivity. Also, sometimes the faster viewing speed brings a new perspective to the operation, and the mechanics of the process become more evident than when viewed at actual, real speed.

In this study, we filmed earth-moving and daily cover operations at landfills. Our time-lapse camera used Super-8 movie film on 50 ft rolls. Although the camera is equipped with variable time settings, we decided a setting of one frame every four seconds would be useful for our analyses, and we stayed with this setting for ease of analysis and comparison between films.

We were able to gather time-lapse data from the following locations in North Carolina: North Wake (Raleigh, Durant Road), Durham City/County, Cumberland County (Fayetteville), Raleigh (US 64 E), Catawba County (Blackburn), and High Point.

B. Landfill Survey

Because of the time and resource limitations involved with intensive time-lapse studies, we concluded that a comprehensive survey would be an appropriate way to gather a large amount of data about landfill daily cover operations. We drafted a rather lengthy, but simple, survey; and sent it to landfill operators throughout the state. The survey and its explanatory cover letter are included at Appendix A. The survey was primarily concerned with questions about daily cover operations, but included other questions on areas relating to or impacted by daily cover operations.

We received an address and phone listing of all permitted landfills in the state from the State Solid and Hazardous Waste Management Branch of the North Carolina Department of Human Resources. They reviewed our survey, and endorsed it with an offical memorandum, included in Appendix B.

We sent the survey directly to landfill operators, thinking that the most meaningful and honest responses would come from those who actually do the work at landfills daily. In actuality, some of the operators received assistance from their county managers, engineers, and finance officers on some of the more technical and cost-oriented questions. Another letter was sent directly to the county managers (Appendix C), informing them of the survey and asking for their support.

Initial response to the survey was encouraging. Of the 173 surveys sent, approximately 40 were returned within a month. After reviewing these, and realizing that not all 40

were exactly what we were interested in, we decided to do a follow-up effort. After pursuing those that hadn't returned the surveys, we found that some had never received them because of improper addresses, postal problems, etc. We drafted a follow-up letter, sent out additional copies, and the response was very positive. Overall, we had some response from 92 landfills, considerably above our expectations for this lengthy, voluntary survey.

Of the 92 surveys returned, 72 were from conventional sanitary landfills, 2 were from power plants, 2 involved industrial textile operations, 3 involved industrial lumber operations, and 13 others involved industries ranging from lithium extraction to the covering of waste flash material once a year. For the purpose of our analysis, we studied only the 72 conventional sanitary operations. Of these, 11 were either closed or not yet operational, further limiting our study to a sample of 61 landfills. We feel this sample accurately represents landfill operations across the state; 61 is a large enough sample for reliable statistical analysis.

C. Site Testing

To find the cost-effectiveness of geotextiles as an alternative method of daily cover, we conducted tests at two very different landfill sites. For the tests, We used a 6-oz/SY nonwoven polypropelene fabric, Supac 6NP, which is manufactured by Phillips Fabric Corporation. A sample is included at Appendix D. Different methods of joining and

placing the fabric were tried to find a reasonable operational technique. We analyzed productivity of these tests with the time-lapse equipment and also a video camera with built-in timer. The actual fabric testing is discussed in greater detail in Section 8.

D. Equipment Cost Estimating

For a meaningful economic comparison of daily cover alternatives, it was necessary to use figures for the equipment component of daily cover operations. Because of the time constraint and great variability of equipment operating costs and accounting procedures between municipalities, we thought more general cost figures would be useful for comparison, and probably more reliable.

We investigated costs figures for the monthly usage rates of scrapers, dozers, front-end loaders, draglines, and graders from standard cost-estimating guides such as Mean's Site Work Cost Data book and the Caterpillar Performance Handbook. We also collected prevailing rental rates of heavy equipment from telephone interviews with rental companies, thinking they would give some indication of the uniqueness of costs in the state. A listing of the rental companies contacted is included in the bibliography.

Conversations with rental companies indicated that they consider landfill applications for their equipment as above average for wear and tear, and if they rented to landfills, they would charge a higher rate--possibly 5 percent higher.

However, we can not consider rental rates as equal to actual operational costs for the average landfill. Rental companies must make a profit, and they must maintain a certain level of availability for their equipment to serve customers. I asked rental agents how much they would adjust the monthly figures for landfill applications and the cost of public vs. private ownership, and most said in the neighborhood of a 10 percent reduction, plus the cost of fuels and top-off fluids and lubricants. The rental rates given were "dry" -- not including the cost of fuel and top-off lubricants.

In addition to the basic owning, depreciation, and maintenance costs, rental rates normally include insurance. Usage is normally limited to 170 or 176 hours per month, and our observations indicate that landfills do not exceed this rate. Thus, if we follow the suggestion of rental agents, we reduce rates by 10 percent, and add fuel and lubricant costs. The Caterpillar Performance Handbook gives a good estimate of fuel and lubricant costs.

The Cat Performance Handbook also gives an hourly operational cost, for everything except interest, taxes, insurance, and labor. Because most governments are self-insured through their taxation powers, and they do not pay taxes on equipment, and they can obtain low-cost loans, these extra costs will not likely increase the operational rate significantly. Labor costs vary greatly and will be treated separately; we will omit them from our cost comparisons for the equipment. In the Cat Handbook, costs are given for each

piece of equipment in the Cat line--for moderate, average, and severe working conditions. From our discussions with rental agents and our field observations, we judged landfill conditions as above average, but not severe.

Comparing these two sources, we found that the rental rates, less 10 percent and plus fluids consistently equalled 1.15 times the average condition figures in the Cat Performance Handbook. I believe this 1.15 times average condition cost is a realistic estimate. It is high enough to account for harsh conditions, yet not so high to neglect factors which may make equipment operation lower for a municipality, such as a lower purchase price from the dealer. Individual costs will naturally vary greatly from site to site; estimating for specific decisions should use any available cost and maintenance records.

5. METHODS OF ANALYSIS

A. Time-Lapse Photography

Using a set camera speed of one frame every four seconds, or fifteen frames per minute, one roll of film can record up to about four hours of continuous operation. Using a time-lapse projector and frame counter, we counted the number of frames (thus the time) that it takes a piece of equipment to make an identifiable cycle, or how long it takes workers to place, cut, and bind a geotextile panel of a given size.

Cycles can be identified in any convenient way, such as every time a scraper passes a given tree, or when it reaches a certain point at the bottom of the working face, completing an entire load, haul, dump, and return cycle. For the fabric, cycle times were pieced together, combining times from easily identifiable operations: rolling out, cutting, binding, and moving fabric given lengths or distances.

In conventional operations, once a sample of cycle times is established, it can be used in combination with the capacity of the equipment and the measured haul distance (if there is a fairly well-established route) to find the productivity. For the fabric, productivity is largely human-oriented, because no heavy equipment is involved.

The productivity of conventional earth-moving equipment can be expressed in standard units, such as cubic yards per hour (CY/hr), for comparisons between different pieces of equipment. This logic and method is best explained using an

example, which follows on the next page. This example is a time-lapse analysis of a Terex TS-14, 14 CY standard scraper.

Going beyond this example, the volume delivered can then be divided by the average depth of cover delivered to find the effective rate of coverage. This methodology is used for the equipment productivity calculations contained in the results sections. An installed cost per square yard is then based on equipment and labor costs for various levels of productivity. An example in the results section uses this technique.

PRODUCTIVITY ANALYSIS
TEREX TS-14 PAN

Location:

Date/Time: 2:47 P.M., 17 Sep 87

Conditions: Mostly sunny, humid, 85 F, dry soil

Description: 10 CY dump trucks bring the soil from off the site one mile away and stockpile it in a flat excavation area. The Terex pan picks up soil from the excavation area and dumps ‘ . the upper portion of the working face, which is approximately 100' x 150'.

Real Time	Elapsed Frame #	Cycle #	# Frames per cycle	Cycle Length
2:47	0			
3:03:26	236			
3:11:45	239	(Camera Move)		
4:22:53	1306	1	97	6:28
	1403	2	98	6:32
	1501	3	111	7:24
	1612	4	94	6:16
	1706	5	166	11:04
	1812	6	117	7:48
	1929	7	96	6:24
	2025	8	98	6:32
	2123	9	134	8:56
	2257	10	127	8:28
	2384	11	114	7:36
	2498	12	98	6:32
5:48:53	2596			

Sample Size = 12 cycles

Sample Mean = 7.5 minutes/cycle

Sample Std Dev = 1.4 minutes/cycle

Productive Time (Start to Park) = 86.0 min = 1.43 hrs

Productivity: $\dfrac{14\text{ CY}}{\text{cycle}}\ \dfrac{(12\text{ cycles})}{1.43\text{ hr}} = 117.2$ CY/hr

Effectiveness: Marginal, trash only partially covered

B. Landfill Survey

This section describes how we compiled and analyzed the survey results. With the aid of a personal computer and a database manager program file, DBASE III Plus, we were able to store all of the results in a convenient format for analysis.

The program enabled us to compute averages and other statistical data for the numerical results. We also created a unique structure and coding system, based directly on our survey questions, to record the answers of the remaining questions. For those familiar with DBASE, the structure of our file is included at Appendix E. It is rather large, with 122 separate fields.

The coding and storage in the program enabled us to rapidly view different combinations of factors to see if there was a relationship between variables. For example, we looked at design factors of the landfill to see if there was any relationship between area and trench methods influencing a shortage of cover material or productivity. The database also allowed us to quickly establish the range of parameters in this large sample from across North Carolina.

Our results from the survey are included throughout the two following results sections, wherever they are appropriate. For instance, we found that 77.0 percent of the landfills used scrapers. Of those that use scrapers, 91.5 percent use elevating scrapers, with an average scraper capacity of 15.3 CY. 91.4 percent had capacities from 11 to 22 CY.

Such statistical information was helpful in modeling costs. From average parameters, we created realistic conditions for a hypothetical landfill, and analyzed the costs of its daily cover operations. Thus, our average model should reflect average costs, because it is based on average parameters found in the survey.

C. Site Testing

Analysis of the fabric testing was similar to conventional analysis in that we used a time-lapse camera to record the work effort, but different because it operated on a smaller scale. Rather than a large operation involving earth-moving cycles throughout the site, the fabric testing concentrated only on the small area where it was needed--the working face.

The analysis was also different because of the experimental and sometimes trial and error nature of the fabric installation. Yet, we were able to obtain basic productivity measures including labor productive time, time per area covered, and eventuallly dollars per square yard covered. The productive time was measured with the time-lapse camera and video camera. The video camera was used as a backup and to record the detailed labor work. Actions that were critical to the placing of fabric may have been missed with the stationary time-lapse; the mobile video camera was used to focus on important details.

6. RESULTS: CONVENTIONAL OPERATIONS

This section includes summary tables of our calculations. It also explains the source of our figures. An effort is made to minimize the display of raw data and focus on the results of our time-lapse analyses.

A. Delay Times

It is essential that the reader understand the meaning behind the results that follow. The productivity figures and costs do not include delay times. We did not gather enough delay information at each site to make definite site-specific delay time predictions. It would have required full-time observation for a week at each site, which was beyond our manpower and time limitations. When we filmed, we tried to film and then analyze **productive** operations. If a dozer operator stopped and talked with his supervisor in a different location from where a scraper was continuing work, we recorded the scraper's work, not the dozer delay.

Occasionally delays occurred in the same area as the productive work, or the productive work stopped altogether, and we were able to record and analyze the delays. However, the delays were very random in their frequency and length. In three samples where we could analyze dozer delays, delays were 18.7%, 11.7%, and 4.5% of total operating time. Of two observations of scraper delays, we measured delays of 22.8%

and 26.3%. In one observation of a dragline delay, we observed a 9.5% delay.

Anyone attempting to use the productivity results that follow should adjust by their own estimation of delay times at their operation. In the absence of available information and based on our experience, we recommend using a 20 percent delay adjustment for each piece of equipment. The 20 percent figure should account for minor maintenance and repairs, supervisory conferences, and other minor or unexplained equipment delays.

B. Elevating Scrapers

Elevating scrapers are the primary tool used in North Carolina for moving daily cover material. Our survey indicates they are used in 70.5 percent of all operations. The average use of elevating scrapers is 18.2 hrs/wk, and daily cover operations constitute an average 57.8% of all productive use of the equipment. The most commonly used scraper is the International Harvester (now Dresser) 412, which is an 11 CY scraper.

Of the many locations using elevating scrapers, we found from direct observations that some sites drive directly over the trash surface to dump the cover; others dump it alongside the working face and allow dozers to spread the cover on the garbage. Nearly all sites use both techniques at one time or another, but one method seems to prevail at each site.

Interviews with operators indicated the reasons for their preferences. Generally, operators who advocate direct dumping

believe it to be more productive because they don't have to move the soil twice. Those who support side dumping believe driving over the trash puts too much wear and tear on their scrapers. Also, they believe it forces soil down into the voids in the garbage unnecessarily, thereby wasting precious cover. Although our survey did not ask which method prevailed at each site, we did time-lapse analysis of both techniques. These results follow.

1. Direct Dumping

This section displays summary results of time-lapse analysis using the direct dumping method. We analyzed this method for two days each at two landfills, and for three days at another landfill. The method is more effective than side dumping, because it minimizes double handling of the daily cover with dozers. The differences are quantified in a following section on dozers. At a very busy landfill, we noticed that direct dumping sometimes interfered with the simultaneous dumping of trash trucks and compaction with trashmasters. When faced with interference from other pieces of equipment, the scrapers usually dumped as close as they could to their target, instead of waiting for the path to clear. It appeared to be a reasonable response to the problem, and did not significantly affect cycle times.

The chart below summarizes elevating scraper productivity results for the three landfills we observed using this method.

Table 6.1

PRODUCTIVITY--DIRECT DUMPING WITH ELEVATING SCRAPERS

Site	Day	#Cycles (n)	Avg Cycle Time $\overline{x}$ (sec)	Sample Std Dev (s)	Total Prod Time (sec)	Equip Capac (CY)	Product (CY/hr)
1	1	7	217	31.0	1516	11	183
	2	17	202	8.6	3432	11	196
	3	58	194	23.9	11240	11	204
2	1	8	460	129	3676	11	86.2
	2	16	413	93.0	6604	11	95.9
3	1	4	332	12.6	1328	22	239
	2	14	332	15.5	4652	22	238

The following chart gives unit costs for each of the three sites above. The average productivity is weighted according to the number of cycles observed in different samples at the same site. The more cycles observed, the greater the weight of the sample toward the average. More extensive research with additional equipment pieces and greater variability of haul distance could be useful for selection of scraper size given different average haul distances.

Table 6.2

UNIT COSTS--DIRECT DUMPING WITH ELEVATING SCRAPERS

Site	Equip Model	Weighted Average Product	Oper Cost* ($/hr)	Delivered Unit Cost ($/CY)	Cover Depth (in)	Delivered Unit Cost (¢/SY)	Haul Dist (ft)
1	Cat 613C	201	28.75	.143	8	3.18	1000
2	Cat 613C	92.5	28.75	.311	5	4.32	1300
3	Cat 623B	238	48.30	.203	6	3.38	1100

* Contains all owning and operating costs, including maintenance, depreciation, insurance, etc. Does not include labor costs or adjustment for delays.

2. Side Dumping with Dozer Spreading

This section includes summary results of time-lapse analysis of the side dumping method. The title of this section is actually somewhat misleading, because even the direct-dump technique described above requires **some** spreading by either a dozer or trashmaster. The distinction is the amount of additional work required for spreading; with side dumping much more dozer spreading is required. Only one site that we observed used this technique; the results are summarized in the charts below.

Table 6.3

PRODUCTIVITY--SIDE DUMPING WITH ELEVATING SCRAPERS

Site	Day	#Cycles (n)	Avg Cycle Time $\bar{x}$ (sec)	Sample Std Dev (s)	Total Prod Time (sec)	Equip Capac (CY)	Product (CY/hr)
1	1	7	460	29.1	3220	15	117
	2	11	530	164	5840	15	102

Again, the productivity in the following chart is weighted according to the number of cycles observed in different samples.

Table 6.4

UNIT COSTS--SIDE DUMPING WITH ELEVATING SCRAPERS

Site	Equip Model	Weighted Average Product	Oper Cost* ($/hr)	Delivered Unit Cost ($/CY)	Cover Depth (in)	Delivered Unit Cost (¢/SY)	Haul Dist (ft)
1	Fiat 161	107	40.25	.376	7	7.31	1500

* Contains all owning and operating costs, including maintenance, depreciation, insurance, etc. Does not include labor costs, or an adjustment for delays, or the cost of dozer spreading. Dozer spreading is analyzed separately in the next section.

3. Dozer Spreading

Medium-sized dozers are frequently used in North Carolina for spreading daily cover material. From our survey, they are used in 44.3 percent of all operations. The average use of dozers is 13.7 hrs/wk, and daily cover operations constitute an average 50.0 percent of all productive use of the equipment. The most commonly used dozers are the Cat D-7's and D-8's, which run in the 200-300 horsepower range.

The dozer productivity chart below includes data from several sites where both side and direct dumping are used. The only site with exclusive side dumping is Site 3 in the chart below. The comparison **should** still be valid because the spreading area includes only the portion of the working face not already covered by another piece of equipment. However, this limited comparison suggests that productivity is only a third to a half with exclusive side dumping. Apparently, there is a great advantage to dumping directly on the garbage with the scraper--the dozers are able to efficiently cover the remaining area much more quickly because the volume and distance of soil to be spread is not as great.

Table 6.5

PRODUCTIVITY--SPREADING WITH DOZERS

Site	Day	#Cycles (n)	Avg Cycle Time $\overline{x}$ (sec)	Sample Std Dev (s)	Total Prod Time (sec)	Area Covered (SY)	Product (SY/hr)
1	1*	11	94.2	14.5	1036	350	1215
1	1**	10	60.0	13.9	600	475	2850
2	1	49	41.7	12.0	2044	1360	2400
2	1***	13	43.7	17.0	568	240	1520
3	1	67	41.7	8.0	2796	625	805
3	2	99	39.1	9.6	3872	625	582

* Pushing **up** approximately 7% grade

>>> Weighted average productivity = 1815 SY/hr

** Pushing **down** approximately 7% grade

*** Rex trashmaster being used like a dozer to spread soil at end of day

Sites 1 and 2 used direct dumping as much as possible. Site 3 used exclusive side dumping and the poor productivity results suggest this method should be avoided.

C. Regular Scrapers

Rather than using elevating scrapers, a few locations are using regular scrapers. From our survey, they are used in 8.2 percent of all operations. The average use of regular scrapers is 17.4 hrs/wk, and daily cover operations constitute an average 42.0% of all productive use of the equipment.

The only advantage claimed by operators of regular scrapers is the greater clearance over the trash when direct dumping. However, the results above seem to dispute that as an actual advantage. One site using this type of scraper also employed dump trucks stockpiling soil from a borrow location one mile away, and a trashmaster to do finish spreading after the direct dump. The results are presented below.

Table 6.6

PRODUCTIVITY--DIRECT DUMPING WITH REGULAR SCRAPERS

Site	Day	#Cycles (n)	Avg Cycle Time $\overline{x}$ (sec)	Sample Std Dev (s)	Total Prod Time (sec)	Equip Capac (CY)	Product (CY/hr)
1	1	12	460	85.7	5400	14	112

Table 6.7

UNIT COSTS--DIRECT DUMPING WITH REGULAR SCRAPERS

Site	Equip Model	Prod (CY/hr)	Oper Cost* ($/hr)	Delivered Unit Cost ($/CY)	Cover Depth (in)	Delivered Unit Cost (¢/SY)	Haul Dist (ft)
1	Terex TS-14	107	41.40	.387	4	4.30	1000

* Contains all owning and operating costs, including maintenance, depreciation, insurance, etc. Does not include labor costs, or an adjustment for delays, or the cost of dozer spreading. Dozer spreading was analyzed separately in the previous section.

1. Regular Scrapers with Direct Dumping and Dump Trucks

We did observe this technique, but the time-lapse film did not yield enough data for a meaningful analysis. A realistic productivity analysis would require time-lapse measurements at both the borrow area and the delivery area. Our survey indicated that relatively few site use dump trucks, only 5 of the 61 locations responding. At those sites, the average use of dump trucks was 21.0 hrs/wk, and daily cover operations constituted an average 66.8 percent of all productive use of the equipment.

Though we do not have productivity results, we can make some general observations abount this technique. First, it is very equipment- and labor-intensive. The operation used a John Deere 544 loader with ripper (for poor soil conditions), an International Harvester TD-20 dozer with ripper, 2 GMC tandem dump trucks, and usually 3 or 4 operators. After the soil was ripped it was loaded into dump trucks with the front end loader. Then it was hauled .7 miles (over considerable positive and negative grades, up to 7%) and deposited in a flat stockpile area toward the lower end of the landfill. From there, a regular scraper loaded the soil and hauled it up a significant positive grade (around 6%) to the working face. The sequencing between the scrapers and trucks did not occur with any regularity. Although we did not accumulate enough data for meaningful productivity and cost analysis, we can safely observe that it was considerably more expensive than other methods. This site requires about twice the amount of

equipment and labor to cover a working face roughly the same size as other operations.

2. Comments about Haul Distance and Dump Trucks

The relationship between haul distance and installed cost per square yard using dump trucks is a highly variable one, dependent on the site conditions and the equipment mix. Realistic productivity figures can only be obtained by a detailed analysis of the specific site. The analysis should include cycle and idle times for each piece of equipment, and a fleet productivity analysis in the case of multiple hauling units. For those attempting to do such analysis, we recommend the Caterpillar Performance Handbook and other productivity references provided by heavy equipment dealers.

D. Dragline

Another technique used for earth-moving is the dragline. Few locations are using draglines; only 9 of the 61 landfills in North Carolina that we received survey results from. Of these nine, only three use draglines for excavating daily cover; the others use their draglines primarily for excavating their sediment ponds. Of those that use their draglines for daily cover, the draglines spend an average of 23.3 hrs/week on daily cover, constituting 96.7 percent of total productive operations.

We were able to time-lapse a dragline excavating daily cover in one operation. The productivity results were impressive.

Table 6.8

PRODUCTIVITY--SIDE DUMPING WITH DRAGLINE

Site	Day	#Cycles (n)	Avg Cycle Time $\bar{x}$ (sec)	Sample Std Dev (s)	Total Prod Time (sec)	Equip Capac (CY)	Product (CY/hr)
1	1	89	53.5	13.6	4764	7	471

The chart above reveals the remarkable productivity of this large piece of equipment. The dragline seemed to be ideally suited for the location and conditions it was being used in. The soil conditions were so poor (dense sandy clay)

that excavation using scrapers was nearly impossible, with frequent breaking of blades despite ripping and push-loading.

Our observation of the operation indicated that a dragline is well-suited for a trench-design landfill operation. The dragline can excavate deep trenches (allowing for greater lift depths) and work well in advance of the dumping and cover spreading area. The dragline we observed was creating stockpiles 20-25 feet high beside the trench. The trench being formed was 20 feet deep and 100 feet wide. The trench walls were nearly vertical because of the soil's stability.

There are several advantages in using a dragline for a trench operation. With a large quantity of cover material stockpiled in advance on either side of the trench, dragline repair does not influence whether or not cover material is available. The lift height and swing width of a large dragline allows it to stockpile material on top of an adjacent cell already filled with several lifts of garbage. Thus, with proper sequencing, it is effective for many lifts beyond the initial one.

Another advantage of the dragline is the nature of the stockpile it can create. Because it stockpiles on the very edge of the trench where refuse is being dumped and compacted, the dozers merely have to pull soil off the edge, and gravity causes a large soil volume to fall into place near to where it is subsequently spread out with dozers.

Table 6.9

UNIT COSTS--SIDE DUMPING WITH DRAGLINE

Site	Equip Model	Prod (CY/hr)	Oper Cost* ($/hr)	Delivered Unit Cost ($/CY)	Cover Depth (in)	Delivered Unit Cost (¢/SY)	Haul Dist (ft)
1	Lima 7yd	471	75.00	15.9	6	2.658	N/A

* This cost figure is strictly an estimate, based on similar large pieces of excavation equipment. We weren't able to find estimating guides that dealt with draglines this large. In any case, this dragline was purchased at a reasonable price because of its age (purchased at 17 years old). The obvious tradeoff is expensive maintenance.

The large initial cost of a dragline might explain why their use is not more widespread at landfills in North Carolina. Some might believe that mobility is also a limitation, because large draglines move very slowly. Yet, if a landfill is well-planned, speed should not be a factor. The dragline basically needs to move at the same rate that the working face progresses down a cell, which is very slow. It does not need to change positions very often because of its large swing range from a fixed position.

The results above suggest that draglines can be cost effective, particularly in poor soil conditions or with trench operations. We encourage their consideration as an alternative excavating tool.

E. Methodology for Determining the Installed Cost of Soil Cover

The methodology outlined below is a very simple one. The degree of details in calculations and estimates can be chosen by the estimator, but the simple methodology will still apply. The method recognizes the two major costs involved in daily cover operations: Equipment and Labor.

1. Equipment Costs

a. List **all** pieces of equipment that are being used for daily cover operations, including excavation, moving, and spreading.

b. Estimate the total productive time (not including delays) in hrs/week that each piece of equipment spends on all operations, daily cover and otherwise.

c. Now estimate the percentage of total productive time that each piece of equipment spends on daily cover. For example, if an elevating scraper in a **typical** week spends 20 hours per week excavating, moving, and placing daily cover; and 5 hrs/week doing other tasks--then 80% of its productive time would be dedicated to daily cover. Multiply by this percentage to determine hrs/week spent on daily cover. These first three steps can be arranged in a tabular format, as shown in a following example.

d. Estimate periodic operating costs for each piece of equipment, in $/hr, month, or year. Most rental agencies use a conversion rate of 170 hrs/month. The degree of detail and level of accuracy for this figure should not exceed the level

in other estimates, or it will be a wasted effort. Several sources are available for this type of information:

1. Actual operating and maintenance costs from existing records--obviously the best possible source.
2. Estimating guides, such as the Cat Performance Handbook. Make assumptions and adjustments to fit site conditions. We suggest using 1.15 times the "average conditions" hourly rate.
3. Rental quotes, particularly if the equipment is rented.
4. Life-cycle cost analysis

e. Determine daily cover equipment costs for each piece of equipment by multiplying the operating cost by the percentage of time used for daily cover.

f. Total all equipment costs spent on daily cover for the chosen time period.

2. Labor Costs

a. List wage rates for all employees, including fringes and benefits.

b. List crew size and composition. Consider that some supervisory time is required for all daily cover operations. The amount and cost of this time will vary, depending on whether the supervisor is a working supervisor, or full time. If full-time, simply estimate the percentage of supervisory time spent on daily cover, and multiply by the wage rate. If

part-time, multiply again by the percentage of time that is spent on supervisory tasks vs. work tasks.

c. If all equipment operators are on the same wage scale, multiply this rate by the hrs/week spent on daily cover in point c. above. This, plus supervisory cost, is the weekly labor cost for daily cover.

d. If wage rates vary, the time that each man spends on various pieces of equipment must be considered. The hrs/week from c. above will then be multiplied for each piece of equipment by the wage rate of the operator of that equipment. The individual products are then summed, and added to supervisory costs, to determine weekly labor costs.

The following example demonstrates the use of this methodology in a hypothethical landfill scenario.

3. Example of Daily Cover Costs with Conventional Methods

The hypothetical landfill scenario that follows is based on average parameters found from the landfill survey. Figures are rounded and adjustments are necessary since it is impossible to operate the average number of 1.59 dozers, or 1.57 scrapers.

a-c. Equipment Mix and Usage

Table 6.10

DAILY COVER EQUIPMENT MIX AND USAGE

Equipment Piece	% of Total Productive Time Spent on Cover	Hrs/week Spent on Cover
Cat 815 Trashmaster	35	15
Cat 613 C Elevating Scraper	60	18
Cat D-7H Dozer	50	14

d. Equipment Operating Costs

From the Cat Performance Handbook, we used "average conditions" rates times 1.15, thus we have:

e.	1 Trashmaster:	(.35) $31.05/hr	(27 hrs/wk)	=	$293.42/wk
	1 Scraper:	(.60) $28.75/hr	(27 hrs/wk)	=	$465.75/wk
	1 Dozer:	(.50) $36.80/hr	(27 hrs/wk)	=	$496.80/wk
f.			Total	=	$1255.97/wk

Labor Costs

a. Wage Rates: $12.00/hr for supervisor, $9.00/hr for others

b. Crew Size: 3 operators, including one supervisor working at half-time, when he operates the dozer for daily cover and other operations. Half of his supervisory time is spent on daily cover operations.

c. Daily Cover Labor Costs:

Supervisor:	(.50) 20 hrs/wk @ $12.00/hr	=	$120.00
Dozer:	14 hrs/wk @ $12.00/hr	=	$168.00
Others:	33 hrs/wk @ $9.00/hr	=	$297.00
	Total	=	$585.00

TOTAL DAILY COVER COSTS FOR LABOR AND EQUIPMENT: **$1840.90/wk**

Productivity/Cost

The obvious question from above is: What is the productivity? It is difficult to say with certainty, because this is a hypothetical equipment mix for an unknown demand. Productivity will depend on the size of the working face and the depth of effective cover. We can use average parameters again as an estimate, but they must be adjusted to reflect the smaller-than-average equipment mix used in our example. Our example used one of each piece of equipment, but the average is 3.10 trashmasters, 1.59 dozers, and 1.57 scrapers per site. If we assume a direct proportion between the number of dozers and scrapers versus the size of the working face covered, our smaller-than-average equipment mix will cover a smaller-than-

average working face. Since the dozer and the scraper are used more frequently for cover than the trashmaster, and since the dozers and scrapers occur in similar numbers per site (1.59 and 1.57), we will adjust the average-sized working face found in the survey by a factor of 1.58. Thus, for this example:

Daily Working Face Area = 12,450 SF / 1.58 = 7,878 SF = 876 SY

Multiplying by 5 days/week, the area covered in one week is 4380 SY. From this area and the total cost, we can determine the cost per square yard of soil in this example.

$1840.90 / 4380 SY = $0.42/SY

Installed Unit Cost : $0.42/SY

Admittedly, this example uses averages beyond what may be justified. The purpose is not so much to get an accurate cost as to demonstrate the method for determining costs. Long haul distances, poor site conditions, and more equipment can be expected in many situations and will naturally drive up the installed cost per square yard.

OTHER PERTINENT SURVEY RESULTS

Our landfill survey yielded many interesting results that haven't been discussed in previous sections. In some cases, without even asking for them, operators candidly shared their concerns about daily cover and other problems at landfills. The majority of this section will summarize results from important survey questions, but a final portion will include operators' concerns about daily cover and other pertinent information, such as the effect of weather on daily cover operations.

To understand the results it is necessary to understand how we asked the questions, so many of the questions are repeated in boldface preceding the results of the question. Not all questions received an equal response rate, so the number responding out of a possible 61 are included. The survey was administered from September-November 1987.

LANDFILL SURVEY

Please answer the following questions as completely as time and available data permit. Include comments, estimates, and explanations in the spaces provided after each question. We are concentrating our efforts on the cost effectiveness of daily cover and to do this, we need accurate data on current operations--including equipment time, maintenance costs, and manhours. Please give accurate estimates no matter how poor production rates may sound. If you only give your best performance rates in best weather with no equipment downtime, it will not help our study. We will be the only ones to see your data. Only data on consolidated averages will be released in our report. We will not reveal your production rates to anyone else so please be as honest and accurate as possible. Thank you for your support!

1. How would you describe the design of your landfill?

____ **Area Method**
____ **Trench Method**
____ **Combination of methods**

Other specifics, such as being in the mounding stage, site bisected by public road, very hilly site, high water table, size of cells, or any other useful description that will help us understand the uniqueness of your site layout and design, and why. We would appreciate a sketch to help us visualize and understand your operation. Please attach a small sketch of the overall layout (or copy of a site plan) and a sketch or profile of the active operating area.

61 responded

24 use area method
17 use trench method
20 use a combination of methods

Approximately one-fourth included sketches or maps

2. Do you currently use or are you moving toward non-conventional technologies in your landfilll operation, i.e incineration, sorting, baling, shredding, etc? When?

58 responded

28 don't use or aren't planning to use these techniques

26 mentioned future use, with the most popular techniques being incineration, sorting, and baling, in that order

3 mentioned current use of sorting, 2 mentioned current use of shredding

3. What is your current average daily tonnage that you are handling? (If tonnage estimates can not be made, use the space provided below to estimate daily volume.)

Our current daily/weekly/monthly/annual (circle one) tonnage is ______________________tons/______. We do/ do not have scales, therefore this is/is not an estimate.

59 responded

Average daily tonnage from all sites = 279.0 tons

The following conversions were made to normalize all data to a daily tonnage basis:

Weekly: divide by 5.5
Monthly: divide by 24
Yearly: divide by 287

Volume answers were converted to tonnage data by assuming a loose truck density of 300 lb/CY and a modern truck density of 500 lb/CY. If the operation was large and had other modern equipment, we assumed modern truck density; if it was a small operation, we assumed loose truck density.

57 responded to the question about scales

11 use scales and have accurate data
46 do not have scales and estimate tonnage

4. At what rate is your tonnage (or volume) increasing? Attach tonnage data from past 5-10 years, if readily available.

Our current demand is growing/declining at a rate of _____%.

47 responded

Average growth rate was 12.45%, quite high. If we ignore as incorrect the 4 responses with unbelievable growth rates of 20% or more, the average is 8.49%. No one mentioned a declining demand.

5. What is the projected life of your landfill, based on its volume-holding capacity?

The current projected volume-life of the landfill is _______.

59 responded

Average volume life = year 2000.3

14 listed volume life <= 1990
27 listed volume life <= 1993
43 listed volume life <= 1998

6. Do you survey the landfill site periodically to keep track of volume use? How often?

_____ No, we do not conduct periodic volume surveys
_____ Yes, we conduct volume surveys about once every ________________ (time period)

57 responded

28 conduct surveys, an average of 9.11 months apart

29 do not conduct surveys

7. Do you foresee permitting or regulatory problems forcing the closure of your landfill? When?

59 responded

10 said yes, they foresee problems

49 said no, they don't foresee problems

Of the 8 who gave a closure date, the date averaged 1992.6

8. Roughly, what is the size of the average working face, that is, the amount that must be covered at the end of each day; and what is the size of the "active" landfill site, those areas still available for additional filling or mounding?

The average size of the working face is ______' X ______'
Our active landfill site covers _________ acres

60 responded
Average size of first dimension = 93.78 ft
Average size of second dimension = 132.75 ft

Thus the average area was 12,450 SF

A majority (34) had both dimensions under 100 ft

The average acreage was 45.9 acres

9. What is your estimate of the volume of soil that is moved daily to cover the working face?

We move approximately _____ cubic yards of cover soil daily

The average volume was 310.57 CY

Using simple algebra with the cover area above, this translates to an average cover depth of 4.45 inches

Almost half (28) move <= 150 CY
11 large operations move => 500 CY

10. What is the actual thickness of soil daily cover that you achieve, on the average? NOTE: No one expects that six inches of soil will always cover the garbage. On the average, it may be more or much less, and it will of course depend on how rough the garbage surface is. In any instance, this question is not intended for any other purposes than research information. Answers will be kept anonymous and confidential!

The average thickness of soil cover achieved is _____ .

All responded, with an average of 5.80 inches

Although we tried to avoid intimidating people, the majority responded with the regulatory depth of 6 inches, contradicting the results of the previous questions.

11. Is your cover soil a suitable cover always, or do you have problems with clayey soils when it gets wet, or rocks? Explain:

60 responded

22 said available cover soil is always suitable
31 said available cover soil is mostly suitable
7 said available cover soil is sometimes suitable

34 mentioned some type of soil problem. Clay and wet soils were the most common problems, followed by rocks

12. The life of some landfills is limited by the amount of daily soil cover material readily and economically available. Are you in this situation, or do you anticipate being in that situation ever at your site?

_____ Yes, daily cover material will determine the life
_____ We anticipate daily cover material becoming a problem in the year ______
_____ No, cover material is readily available, and will not affect the life of our site

58 responded

18 said that cover soil would limit the life
14 gave a year estimate, averaging 1990.4
40 said cover soil will not limit the life

Of those that said soil would limit, their average volume-life was 1992.5. For those that said it wouldn't limit, average volume-life was 2004.4. This supports our belief that many operators don't become aware of cover limitations until late in the landfill's life.

13. What is the average haul distance from where your soil cover is excavated to where it is placed on the working face? Estimate if necessary.

Our average haul distance is ___________________________

59 responded, with an average haul distance of 1761.5 ft

Neglecting one very long haul distance (10 miles), the average haul distance was 881.6 ft.

Several attempts were made with the aid of Lotus plots to determine relationships between haul distance, landfill life, and other variables. No definite relationships were found, apparently because of too many independent variables affecting haul distance, including site conditions, site planning and organization, and landfill design. No one factor yielded a consistent relationship with haul distance.

14. Is the excavation for cover material off-site, or do you purchase borrow material from elsewhere?

59 responded

54 excavate on-site

4 excavate off-site

1 purchases borrow material from contractors, but did not include a borrow cost

15. From our recent observations of landfill operations, we have noticed that rains and mud can totally prevent the trash from receiving any daily cover, unless an excess of soil happens to be stockpiled nearby. How many days per year would you estimate that bad weather prevents the trash from being covered?.

Because of bad weather, the trash is not covered ____ days/yr

49 responded, with an average of 29.8 days/yr

3 claimed weather delays of 100 day/yr or more

Ignoring those three as excessive, the average was still 24.35 days/yr

16. Please list your current equipment fleet by checking the appropriate spaces below:

Equipment	Quantity	Model/Capacity	Age (yrs)
Trashmasters	Avg = 3.10	Rex 350	Avg = 7.78
Dozers	Avg = 1.59	Cat D-7	Avg = 8.60
Front End Loaders	Avg = 1.43	IH 250, IH 195	Avg = 7.81
Scrapers	Avg = 1.57	IH 412	Avg = 7.68
Elevating			
Regular			
Other (i.e. Draglines)			
Dragline	Avg = 1.56	Bucyrus	Avg = 14.7
Motor Graders	Avg = 1.05	Galion	Avg = 13.7
Dump Trucks	Avg = 2.75	Not Avail	Not Avail

A few backhoes, rubber tire loaders, and farm tractors with blades were also mentioned

Average statistics for each type of equipment are given above in the appropriate location

The average total number of equipment pieces = 5.82

17. Do you anticipate any changes in your equipment mix, or are you trying to upgrade or change it?

Explain:

59 responded

39 said yes, they are trying to upgrade
20 said no, their current mix is sufficient

18. The application of soil daily cover often involves several pieces of equipment. The same pieces of equipment are also used for construction and maintenance of haul roads, sedimentation ponds, and drainage ditches. Considering all the activities of a piece of equipment, estimate the total time and percentage of time specific pieces of equipment are used for moving daily cover relative to all other tasks. For example, if an elevating scraper in a typical week spends 20 hours per week excavating, moving, and placing daily cover; and 5 hrs/week doing other tasks--then 80% of its productive time would be dedicated to daily cover.

NOTE: This is a difficult question to answer accurately, so simply make your best educated guess--based on your experiences and opinions of equipment operators and supervisors. Obviously, a rainy spell might require more than average time spent on road maintenance. We're concerned with average times over the course of a year.

Equipment	**Hrs/week spent on Daily Cover Operations**	**% of Total Productive Time**

In addition to the results given in previous sections, the following data was gathered from equipment that we didn't observe:

Trashmasters: used for daily cover in 12 operations

Avg = 14.7 hrs/week 34.6%

Front End Loaders: used for daily cover in 37 operations (predominantly the smaller ones)

Avg = 13.2 hrs/week 51.6%

Hydraulic Excavator: used for daily cover in 1 operation

15 hrs/week 80%

Compiling individual statistics yielded an average of 2.72 pieces of equipment per operation used for daily cover, an

average of 15.69 hrs/week, for a total weekly rate of **42.6 hrs/wk**. This compares favorably with the results of Question 20 below.

19. Most equipment operators perform different tasks on different pieces of equipment throughout the day. Do you have operators that are dedicated to only one piece of equipment, or do they run various pieces, depending on what is needed at the time? Briefly explain your operator/equipment arrangement, including crew size:

58 responded

14 use dedicated operators

44 rotate operators on various equipment

Average crew size was 3.6 equipment operators;

8 locations were small enough to use only one operator

3 locations had seven or more operators

20. Considering your response to the previous question, estimate (based on your experiences of the past year) the average number of man-hours/week spent in fulfilling the requirement for soil daily cover. Consider poor production periods as well as smooth operating procedures. Include the portion of supervisors time spent in this area.

Total man-hours per week spent on daily cover: ___________

Total man-hours per week spent for all activities at the landfill: ______ (Do not include office and scale personnel, but include supervisory time on the site).

60 responded

Average daily cover man-hours per week = **41.92**

Average total hours at landfill = 177.51

Note that the total time would include idle time. With a 20% idle time, this indicates that 30% of the total labor time at landfills is spent on daily cover.

The remaining questions gave us some limited information that could be used in further research, including what type of cost records were available and whether the landfill operators would be willing to share them for research purposes. Interspersed throughout the surveys were voluntary comments made by operators that deserve mention.

Operator's Comments

One operator described their daily cover operation as being "in a crisis situation," and the landfill was about to be closed, with no new site chosen or permitted.

Another operator complained that the six-inch daily cover requirement was unrealistic, and that it couldn't be done economically. Our field visits confirmed the difficult situation at several sites.

It seems that operators avoid using six inches when they can, or any time soil conditions are wet. However, where adequate funding and conscientious management exist, the six inches is actually exceeded on a regular basis. Some sites have excess cover stockpiled, and they tend to use it generously early in the life of the landfill.

Recently, the EPA has been moving toward greater involvement in enforcing the daily cover requirement. In the near future, operators could be forced to use more soil than they are now.

8. RESULTS OF FABRIC TESTING

The results in this section are a combination of field observations and time-lapse/video analysis.

A. High Point Feasibility Study

An initial feasibility test of geotextile fabric was done at High Point, NC in July 1987. Several lengths of fabric 75-100 feet long were placed on top of the working face to see how it performed as a daily cover. General observations were made of the fabric's trafficability the day after it had been placed. The fabric retained its basic integrity even with repeated (30-40) passes of a trashmaster. Garbage trucks generally did not affect the fabric, with one exception. Where the trash was not well-compacted or settled under the fabric, the weight of one truck sinking into the refuse brought the fabric near the truck's exhaust pipe, melting the fabric and creating a hole approximately 4 inches in diameter. The fabric application method described later will avoid this problem.

Anchoring the fabric to the garbage was also attempted. One method used 10-inch steel wire rods with a 1-inch washer on one end to hold the fabric in place. Another method used 10-penny nails. Both methods were largely unsuccessful, because it was impossible to locate refuse under the fabric that was in the right place and of the right size and consistency to actually hold the fabric. Also, these two methods resulted in the fabric edge being exposed on top of

the garbage, and the trashmaster accidentally caught the edge when pushing garbage on top of the fabric the next day.

A small amount of soil was tried as the final anchoring method, and this seemed to be successful. Thus, initial feasibility tests concluded that a small amount of soil placed around the edges of the fabric would serve as a sufficient anchor. This technique also seemed to minimize the chance of a trashmaster blade getting under the fabric edge and pulling it out of place.

B. Catawba County Test Week

During the week of October 19, 1987, more detailed and controlled tests of the fabric were conducted. The series of tests were aimed at finding the optimum method for binding together the fabric and installing it over the refuse. Four different binding techniques and numerous installation tests were conducted during five consecutive days of testing.

Binding and installation of the fabric was done using several steps in a logical sequence. First, a 15 ft by 300 ft roll was removed from a truck and placed to align with one edge of the working face. Then it was rolled out the width of the working face and cut to length. Next, the same roll was rotated end-for-end and then rolled out directly on top of the first piece, and cut. These two pieces were then joined along one edge using one of several binding techniques, forming a 30 ft wide panel. The panel was then folded and transported to the working face where it was bound to fabric already in place. The panel was then moved over the refuse and secured along the edges with dirt or tires.

Occasionally, more than two pieces were rolled out on top of each other, and they were bound on alternate sides of the stack, accordian style. However, we recommend binding only two pieces at a time to facilitate easy transport.

The crew size was normally two workers. Where assistance was received from additional workers, appropriate adjustments are made in the following analysis to reflect productivity of a standard crew size of two.

The results below are organized by the binding technique used and the day of application. Site and weather conditions are included, as they influenced productivity of the mostly manual techniques.

DAY 1: TESTING OF METHODS 1 AND 2

Conditions: Clear, sunny, 70-75^0 F, work from 2:15 to 4:00 P.M. Stable, relatively flat soil assembly area. Landfill working face 115 ft x 75 ft.

Method 1: Tatch-it Plastic Ties

This method used small plastic ties, similar to those used in department stores to attach price tags. A $25.00 gun with a "needle" pierces the fabric to install the ties. Because these ties have limited strength, three were used per hole, at a 6-inch spacing. Cost of the ties was $2.95 per 1000.

1. Work Samples/Productivity

Sample 1: 2 workers bound 35 ft in 424 sec

Binding Rate = .0825 ft/sec

Sample 2: 2 workers bound 175 ft in 1032 sec

Binding Rate = .1696 ft/sec
(indicates rapid learning curve)

2. Conclusions

Although the binding rate improved significantly on the second trial, it is doubtful that the rate would increase much more because the work was done under optimal flat surface

conditions and optimal weather conditions for worker comfort. Therefore,

The Assumed Binding Rate = .170 ft/sec

A disadvantage of this method is that it requires the workers to crouch or be on their knees. The necessity of three ties per hole also suggests that the ties are not strong enough. A final disadvantage is that it leaves 6-inch gaps along each seam, allowing vector penetration.

Method 2: Gluing with Spray Glue

This method used a 17 oz. can of 3-M 77 spray adhesive, which costs $5.00 per can. One can will bind together approximately 150 ft of fabric. The glue was sprayed along the edge of one fabric panel, allowed to dry, and then bonded to another panel.

1. Work Samples/Productivity

Sample 1: 3 workers bound 75 ft of fabric in 1112 sec

Normalizing to the size of a 2-person crew,

Binding Rate = (2/3) .0674 = .045 ft/sec

2. Conclusions

Although only one sample was tested, it was obvious that this method would be cumbersome and time consuming. The glue was quite expensive, and did not bind very well--even under what could be considered optimum drying conditions.

Therefore,

The Assumed Binding Rate = .045 ft/sec

DAY 2: TESTING OF METHOD 3

Conditions: Clear, sunny, 60-65^0 F, work in the A.M. Stable, relatively flat soil assembly area. Landfill working face 115 ft x 75 ft. No binding in P.M. because of abundance of bound fabric relative to the demand on the working face.

Method 3: Metal Hogrings

This method used standard hogrings and hogring pliers. Because the metal is very strong, spacing could be extended to 18 inches. The cost of hogrings was $1.69 per 100.

1. Work Samples/Productivity

Sample 1: 2 workers bound 85 ft in 880 sec

Binding Rate = .0967 ft/sec

Sample 2: 2 workers bound 120 ft in 1016 sec

Binding Rate = .1181 ft/sec

Sample 3: 3 workers bound 105 ft in 680 sec

Normalizing to a 2-person crew size,

Binding Rate = (.67) .1544 = .1029 ft/sec

2. Conclusions

This method has many of the same disadvantages as the plastic Tatch-it, except the gaps in the seam are much larger, making vector penetration quite probable. Although the binding speed picked up on the second sample, it would not likely proceed much faster. Conditions were very favorable, and hand fatigue using the hogring pliers could become a

problem with long binding distances. This method also requires the workers to kneel or crouch. Therefore,

The Assumed Binding Rate = .120 ft/sec

DAYS 3, 4, and 5: TESTING OF METHOD 4

Conditions:

Day 3: Cool, 50-55° F, overcast and very windy.

Day 4: Warmer, 55-60° F, sunny with light wind.

Day 5: Warm, 65° F, sunny.

Most of the fabric panels were joined on a flat and stable earth surface, but some were joined to panels already covering garbage, and the workers had to walk on spongy garbage. Working face size varied, from 100-110 ft in one dimension to 70-80 ft in the other dimension.

Method 4: Sewing with Electric Sewing Machine

This method used a small portable generator and an industrial-type sewing machine. The machine makes a ravel-stitch similar to that seen on bags of dog food or softener salt. The seam was generally sewn about 2-3 inches from the edge of the fabric. The sewing machine costs approximately $500. One roll of thread would last about two weeks for the amount of binding required at the test site.

On Day 3, high winds forced the workers to use tires as deadweights to hold the fabric in place while it was being sewn. As the sewing progressed along a seam, and a worker approached a tire, he would toss it aside, feed the fabric in, and then pause to replace the tire after sewing. This inconvenience slightly decreased productivity, but not by a readily measurable amount. The use of old tires in windy

conditions is a good solution, as there is usually an adequate supply at most landfills.

Because the sewing method seemed to work well and it provides a continuous seam, it was tested extensively. The chart below summarizes sewing work samples. Many of the samples used a third man, supporting the fabric after the sewing machine pass. However, this third man wasn't really necessary. He appeared to only marginally increase productivity, no more than 10 percent. Hence, where a third man is used, productivity will be decreased by 10 percent to normalize to a 2-person crew size for purposes of comparison.

1. Work Samples/Productivity

Table 8.1

WORK SAMPLES OF FABRIC BINDING BY SEWING

Day	Sample	Crew Size	Length (ft)	Sewing Time (sec)	3->>2-person Productivity Adjustment (Time x 1.1)	Binding Rate (ft/sec)
3	1	3	80	256	281.6	.2841
3	2	3	80	176	193.6	.4132
3	3	3	80	165	181.5	.4408
3	4	3	80	180	198.0	.4040
3	5	3	80	141	155.5	.5158
3	6	3	80	162	178.2	.4489
4	7	2	100	173	--	.5780
4	8	2	92	172	--	.5349
4	9	2	100	*220	--	.4545
5	10	3	100	*256	281.6	.3551
						$\bar{x}$ =.4429
End-to-end fabric splices (all 15 ft widths)						
3	1	3	15	39	42.9	.3497
4	2	2	15	**112	--	.1339
4	3	2	15	60	--	.2500
5	4	2	15	72	--	.2083
						$\bar{x}$ =.2355

* On garbage, sewn to existing panel

** Includes machine readjustment

2. Conclusions

a. A wide variety of conditions were encountered, including high winds and sewing directly on top of garbage. This sample is likely to be representative of future field conditions.

b. Sample #9 demonstrates that average productivity can be achieved while walking on garbage with only 2 workers.

c. Observations and analysis suggest that the speed of this method is largely machine-driven. Machine adjustments will slow the process, but were **very** infrequent during the three days of sewing.

d. End-to-end splicing of the 15-ft fabric went at a considerably slower speed than sewing along the edges. We attribute this to the often uneven end cuts that made feeding the machine more involved and the more awkward worker positioning, where they were standing on the fabric being sewn, instead of to the side. A different method that might overcome this problem is suggested in the recommended procedures portion later in this section.

e. Worker comfort and the sewing rate appear better when sewing is done on a relatively flat, stable surface. Compacted garbage should be acceptable.

f. Because the samples are thought to closely resemble the adverse conditions that might be encountered preparing fabric for daily cover, we can assume:

Binding Rate = 0.440 ft/sec (Along the edge)

= 0.240 ft/sec (End-to-end splicing)

DAYS 1-5: FABRIC ACTIONS OTHER THAN BINDING

All of the binding methods described above require other actions before becoming installed daily cover. The other processes include rolling out the fabric before binding, cutting the fabric to the desired length, rolling or folding up the bound fabric panels to make them transportable by the workers, and then actually moving the fabric onto the working face and covering the trash. Our time lapse analysis considered each of these processes separately, so we will devote a separate section to each process.

Rolling Out the Fabric

Before the fabric was rolled out, it was removed from the back of a pickup truck by two men. The roll size was 15 ft wide, with 300 ft of 6-oz Supac on each roll. The roll size and weight of 195 lbs makes it an acceptable size for two people.

Once a roll was positioned on the ground, the workers rolled it out by pushing it with their feet or hands. Like the sewing described above, a third man sometimes assisted in rolling out the fabric, but he was not needed. Two men can very easily roll out the fabric and keep it in correct alignment. We will account for any marginal assistance provided by a third man with a 10 percent adjustment.

The chart below summarizes productivity results for rolling out the fabric. On Day 5, no fabric was rolled out

because a sufficient amount for cover had been prepared the previous day.

Table 8.2

WORK SAMPLES OF ROLLING OUT FABRIC

Day	Sample	Crew Size	Length (ft)	Rolling Time (sec)	3->>2-person Productivity Adjustment (Time x 1.1)	Rolling Rate (ft/sec)
1	1	3	50	64	70.4	.7102
2	2	2	80	92	--	.8696
3	3	2	80	92	--	.8696
3	4	2	80	148	--	.5405
3	5	2	80	76	--	1.0526
3	6	2	60	96	--	.6250
3	7	2	20	20	--	1.0000
3	8	2	80	89	--	.8989
3	9	2	80	161	--	.4969
3	10	2	80	88	--	.9091
4	11	2	100	153	--	.6536
4	12	2	100	106	--	.9434
4	13	2	100	77	--	1.2987
						$\bar{x}$ = .8360

The variability in roll-out speeds is most likely attributed to the roll size--as the roll gets smaller, it is lighter and easier to position and roll out. The sample mean above should give a realistic estimate over time. Therefore,

The Assumed Roll-Out Rate = 0.84 ft/sec

Cutting the Fabric

All of the binding methods also required cutting the fabric to size. The 15 ft cut was always made by one man, using a utility knife. He leaned down and made consecutive cuts the length of his arm swing.

The chart below summarizes productivity results for cutting the fabric. On Day 5, no fabric was cut because a sufficient amount for cover had been prepared the previous day.

Table 8.3

WORK SAMPLES OF CUTTING THE FABRIC

Day	Sample	Crew Size	Length (ft)	Cutting Time (sec)
3	1	1	15	28
3	2	1	15	36
3	3	1	15	20
3	4	1	15	15
3	5	1	15	23
3	6	1	15	42
3	7	1	15	32
4	8	1	15	24
4	9	1	15	32
4	10	1	15	43
4	11	1	15	17
4	12	1	15	12
				$\bar{x}$ = 27.0

The variability in this sample was probably most influenced by the worker's motivation at the moment. Sometimes the worker appeared to be in a hurry to get it cut; other times he was not. Sometimes the cutting went slower because the worker positioned himself relative to the large roll where it was not easy to get a good arm stroke.

Gathering the Fabric

When the fabric is bound together accordian-style, bound panels form a stack on the ground 15 ft wide. From this position we observed two techniques of gathering the fabric into a smaller size: rolling and folding.

Depending on the length of the panels, wind conditions, and the number of panels sewn together, it is possible to drag the fabric directly from an assembly area to the working face. However, it is usually easier for two workers to handle if the fabric is gathered to a size smaller than 15 ft, so they can grasp their arms around it. Several attempts were made at gathering the fabric, but no one method was used with any consistency of crew size or gathering technique. Nonetheless, the results below should give some indication of possible productivity for gathering.

Table 8.4

WORK SAMPLES OF GATHERING THE FABRIC

Day	Sample	Crew Size	Panel Size (W x L)	Gathering Time (sec)	Gathering Rate (SF/sec)	Gathering Rate (SY/sec)
Rolling						
1	1	3	30 x 100	142	20.27	2.25
3	2	4	105 x 80	720	11.67	1.30
4	3	3	15 x 100	158	9.49	1.06
						$\bar{x}$ = 1.53
Folding						
4	4	2	30 x 100	480	6.25	.69

Although the samples indicate that rolling is more productive than folding, it is doubtful that this will hold true in repeated tests. The rolling of fabric appeared to be very time consuming and tedious. Rolling must occur along the entire width of the working face, and can be difficult for 2 men to accomplish--they must constantly change positions along the roll. Only one sample of folding was observed, so no real conclusions can be drawn. Instead, we recommend a loose gathering, possibly with 2-3 large folds across a 15 ft width. A greater or lesser amount of folding should occur in response to existing wind conditions. With this limited study, though, we can only follow the results that are available. Therefore,

The Assumed Gathering by Rolling Rate = 1.5 SY/sec

The Assumed Gathering by Folding Rate = 0.7 SY/sec

Moving the Fabric

Like the gathering of fabric, there was little consistency between samples of moving fabric. Before moving panels on Day 3 high winds forced gathering of the fabric to a size where it wouldn't be caught by the wind. Sometimes moving the fabric and covering the garbage proceeded simultaneously, but we will cover spreading/covering separately below.

Table 8.5

WORK SAMPLES OF MOVING THE FABRIC

Day	Sample	Crew Size	Panel Size (W x L)	Moving Time (sec)	Moving Distance (ft)	Moving Rate (ft/sec)
1	1	5	30 x 105	72	40	0.556
3	2	4	80 x 105	210	160	0.762
4	3	1	45 x 100	68	75	1.103
4	4	2	15 x 100	96	175	1.823
5	5	2	15 x 100	220	80	0.364
5	6	2	30 x 100	112	30	0.268
						$\bar{x}$ = 0.813

Because testing went on all day, there was usually no motivation to move the fabric quickly. Sample 3 above suggests that even one worker can move fabric quickly if he chooses to. The sample mean reflects a very comfortable working rate, and it includes moving some large panels--which is something we do not recommend.

Spreading the Fabric/Covering the Refuse

Like the two previous methods, there was little consistency between samples of spreading fabric. Spreading was done with various methods. Sometimes it was unfolded, sometimes it was held in the breeze to assist spreading, and sometimes it was pulled at ground level. Because either process has the same objective, we chose to present the sample results in one area.

Table 8.6

WORK SAMPLES OF SPREADING/COVERING THE FABRIC

Day	Sample	Crew Size	Panel Size (W x L)	Spreading Time (sec)	Spreading Rate (SF/sec)	Spreading Rate (SY/sec)
Unfolding						
1	1	3	30 x 100	142	20.27	2.25
3	1	4	105 x 80	180	46.67	5.19
4	2	3	30 x 100	43	69.77	7.75
4	3	2	30 x 100	60	50.00	5.56
						$\overline{x}$ = 6.16
Unfolding and Covering						
4	1	2	30 x 100	166	18.07	2.01
5	2	2	45 x 100	324	13.89	1.54
						$\overline{x}$ = 1.78

Different responses will be appropriate for differing conditions, but we can safely say that the unfolding productivity figures above can be repeated in practice. The

unfolding over the garbage was more cumbersome than the combined moving and covering in the previous section. We recommend using the previous moving rate since it was a better technique.

Idle and Contributory Time

In addition to the above processes, fabric as a daily cover requires contributory time for things such as walking to get the sewing machine, and starting the generator. Like most processes, it also includes delay and idle time, and these times must be considered in the productivity analysis.

Several observations were made of continuous work--where fabric was unloaded, unrolled, cut, sewn, unrolled, cut, sewn, etc. From these observations, we can get an idea of the percent idle time. "Idle time" here is defined as any time fabric is not being moved, rolled out, gathered, unfolded, cut, spread out, or sewn. Thus, idle time will include contributory work such as walking to get the sewing machine, starting the generator, and laying out an extension cord.

In one series of processes, six 80-ft panels were unrolled, cut, and sewn together. In that sequence, (from the first roll being unloaded from the truck to the end of the sixth roll being sewn) 61.8% of the time was idle or contributory work. 38.2% was active, effective work on the fabric. With an average crew size of 2.5, and an 80' x 75' panel formed, the entire sewing process occurred at a rate of:

$$\frac{2400 \text{ SF}}{(3822 \text{ sec})\ (2.5 \text{ workers})} = 0.628 \text{ SF/sec/worker}$$

Another sequence included rolling out, sewing, cutting, unfolding, folding, rolling out, cutting, sewing, unfolding, rolling up, rolling out, sewing, unfolding, and rolling up--

essentially binding together and gathering four 15' x 100' panels. Though we weren't able to determine the entire breakout of idle time, the whole operation required 4280 seconds, which included a sewing machine readjustment. With a two-person crew, the work rate for binding and gathering was:

$$\frac{6000 \text{ SF}}{(4280 \text{ sec})\ (2.0 \text{ workers})} = 0.701 \text{ SF/sec/worker}$$

A final sequence involved sewing three 15' x'100' panels. It included rolling out the 3 panels, 3 cuts, and sewing 2 seams. It required 1404 sec for 2 workers, for a binding rate of:

$$\frac{4500 \text{ SF}}{(1404 \text{ sec})\ (2.0 \text{ workers})} = 1.603 \text{ SF/sec/worker}$$

In this sample, idle and contributory time was 43.3%.

The great variance in productivity between these few continuous samples can be **partially** attributed to the conditions. The first sample was on Day 3, with high winds. The variance can also be explained by the varying sequence of operations and different processes involved. The second sample included gathering the fabric by rolling it in a small roll--which was really unnecessary. Production will naturally decrease when unnecessary folding, unfolding, or rolling is interspersed with the necessary rolling-out, cutting, sewing, and moving.

The third sample suggests that productivity can increase when only two men are working. With only two workers, cooperation and coordination seemed to increase. Overall, our observations suggest that **two** workers can join and gather the daily cover at a rate of 1.5 SF/sec.

Installation Procedures

From the many methods tried during a week of fabric testing, a consensus was reached between the workers and observers about the best installation method for the fabric. It is outlined below, and followed by several recommendations and comments from the landfill personnel at the test site. The information below was compiled by Dr. Richard R. Rust from meetings held after the fabric test week at Catawba County.

1. Roll fabric out width-wise on plateau of previous day's covered refuse.
2. Cut.
3. Roll another panel on top of first panel.
4. Cut.
5. Sew Seam.
6. Fold accordion style.
7. Two-man carry to top of working face.
8. Sew seam to last existing panel at top of face.
9. Unfold to base of working face at end of day.
10. Secure edges with tires or soil.
11. Fold back to continue filling at start of day.
12. If fabric can't be folded back and pulled up the face (i.e. wet or tacked down the previous day with soil), attach next sections to crown of fabric from previous day's filling.

Observations:

1. This system becomes difficult in windy conditions. Tires or similar deadweights are necessary to hold the fabric down.

2. All field work should be conducted while standing on fabric to facilitate operation and prevent possible injury.

3. Seaming while standing on refuse did not produce neat results. Prefabrication of pre-sewn panel blankets would produce better quality control.

4. Sewing is a better method of attaching panels than glue, hog-nose rings, or Tatch-it plastic fasteners. Sewing provides a continuous gap-free blanket. The glue used did not adhere well. Seam gaps are inherent in the remaining methods, which allows vector access to refuse, more odor problems, and a greater chance for wind to rip seams. Hog-nose or Tatch-it gun plastic fasteners may be the best way to conduct touch up fastening of split seams and rips. Hog-nose and Tatch-it guns will have to be used on the overlap seams where a bite in the fabric can not be gathered for sewn seaming.

5. At the end of the day, the blanket of sewn-together widthwise panels can be pulled down over the working face.

6. No more than two panels should be sewn together in prefabrication of blankets to facilitate manual movement to the working face (limitation of two-man carry for a hundred foot wide two panel blanket held on each end). The blankets should be folded and gathered if transported in the wind.

7. If wet, two sewn panels may be too heavy for a two-man carry. Fabric should be protected from water until placed with tarps or plastic.

8. Transporting sewn-together panel blankets by rolling them over the trash is unwieldy because of to undulations in refuse and length of roll (typically 75-80').

Comments from Landfill Personnel

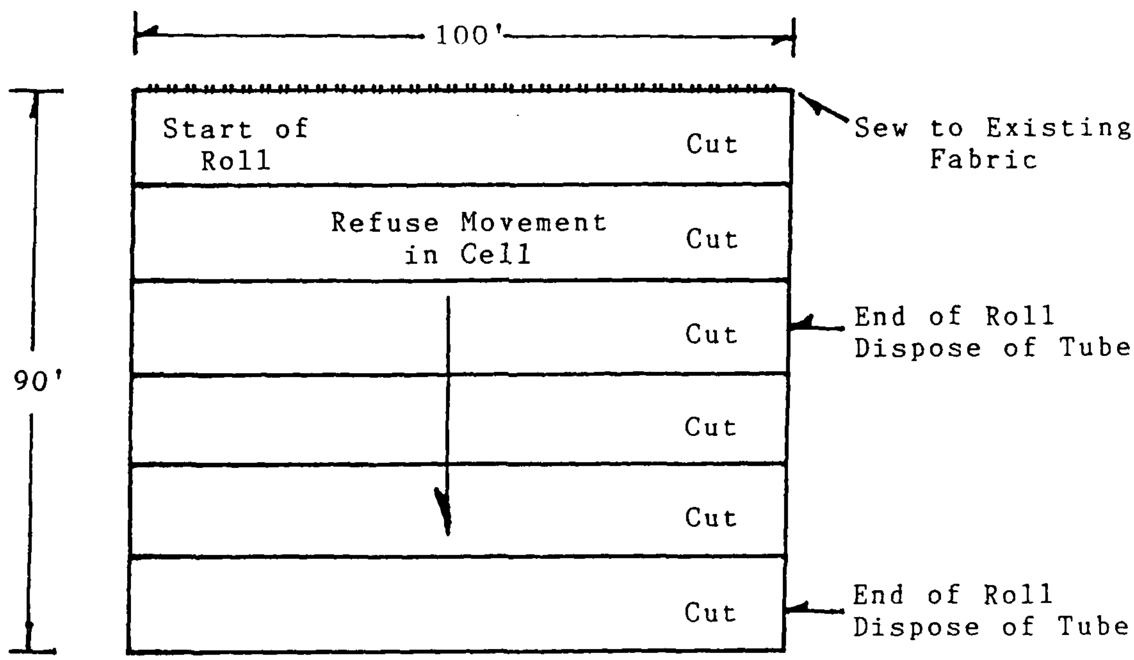
Landfill personnel indicated they would not advocate fabric method if it requires extra work for them (especially manual labor). They would support it if it wouldn't require additional work on their part.

C. An Example Site: Estimating Cost of Fabric Installation

From our preceding analysis of rolling out, sewing, cutting, gathering, unfolding, and spreading/covering times, we can estimate productivity and costs for a hypothetical daily cover operation. We will assume an average-sized working face, 100 ft x 90 ft. The configuration of the panels in place is shown below.

Figure 8.1

EXAMPLE FABRIC CONFIGURATION



The assumed fabric for this example is Phillips Supac, a nonwoven polypropelene fabric (See Appendix D). Because the 6-oz fabric rolls come in 300 ft x 15 ft rolls, no end-to-end fabric splicing would be required. To avoid splicing with other area sizes, either cell width or the length of the roll ordered from the factory could be adjusted.

As mentioned in the preceding procedures section, we recommend that only two panels at a time be sewn and moved to the top of the working face. We will assume the binding area is 100 ft from the top of the working face, perhaps at an adjacent cell where the refuse has settled, providing a stable and relatively flat working platform.

The time sequence of operations can be estimated from our previous analyses. The work rates for a two-person crew that will apply in this scenario are:

Rolling out:	0.84 ft/sec
Cutting (15 ft):	27.0 sec
Sewing:	0.44 ft/sec
Unfolding:	6.2 SY/sec
Moving panel over refuse:	.80 ft/sec
Contributory and Idle Time:	Assume 55%

Although it was never measured, we will assume disposal of the carboard tube in the center of the roll requires a time equal to cutting 15 ft of fabric, 27 seconds. The following chart summarizes all necessary actions for this example:

Table 8.7: WORK PROCESSES FOR EXAMPLE FABRIC DAILY COVER

Action	Work Rate	Quantity	Time (sec)	Cum Time (sec)
Unroll Panel 1	.84 ft/sec	100 ft	84	84
Cut Panel 1	--	15 ft	27	111
Unroll Panel 2	.84 ft/sec	100 ft	84	195
Cut Panel 2	--	15 ft	27	222
Sew 1 to 2	.44 ft/sec	100 ft	44	266
Unroll Panel 3	.84 ft/sec	100 ft	84	350
Cut Panel 3	--	15 ft	27	377
Unroll Panel 4	.84 ft/sec	100 ft	84	461
Cut Panel 4	--	15 ft	27	488
Sew 3 to 4	.44 ft/sec	100 ft	44	536
Unroll Panel 5	.84 ft/sec	100 ft	84	616
Cut Panel 5	--	15 ft	27	643
Unroll Panel 6	.84 ft/sec	100 ft	84	727
Cut Panel 6	--	15 ft	27	755
Sew 5 to 6	.44 ft/sec	100 ft	44	798
Move 1 & 2 to Face	.80 ft/sec	100 ft	80	878
Sew to existing	.44 ft/sec	100 ft	44	922
Unfold/Cover Face	6.2 SY/sec	333 SY	54	976
Move 3 & 4 to Face	.80 ft/sec	100 ft	80	1056
Sew to Panel 2	.44 ft/sec	100 ft	44	1100
Unfold/Cover Face	6.2 SY/sec	333 SY	54	1154
Move 5 & 6 to Face	.80 ft/sec	100 ft	80	1234
Sew to Panel 4	.44 ft/sec	100 ft	44	1278
Unfold/Cover Face	6.2 SY/sec	333 SY	54	1332

Since we assumed an idle time of 55 percent, active time is only 45 percent of the total. Therefore, the total time for the entire covering operation is:

$$\frac{1332 \text{ sec}}{.45} = 2960 \text{ sec, or } 49.3 \text{ min}$$

For this example, the rate of daily cover for a two-person crew would be:

$$\frac{100 \text{ ft} \times 90 \text{ ft}}{2960 \text{ sec}} = 3.04 \text{ SF/sec, or } 0.338 \text{ SY/sec}$$

Now we can calculate costs. We will assume a wage rate of $9.00/hr and a fabric cost of $0.62/SY delivered to the site. Therefore:

Labor Cost: 2 workers @ $9.00/hr for 50 min = $15.83

Material Cost: 1000 SY of fabric @ $0.62/SY = $620.00

Total Cost for 1000 SY cover = $635.83, or

Unit Cost ≈ $0.636/SY

Note: This installed cost per square yard does not include the cost of a small amount of soil around the edges to secure the fabric. It also does not include the costs mentioned below that would be part of a continuous fabric cover operation:

1. Amortized storage costs

Fabric needs to be stored under cover to stay dry

2. Amortized equipment requirements:

   a. Sewing machines

      $500 purchase price for ravel-stitch machine

      $1000 purchase price for lock-stitch machine

   b. Generator

      $500 purchase price

   c. Extension cord

   d. High-top steel shank leather boots (for worker safety)

3. Expendables

   a. generator fuel

   b. thread

4. Equipment maintenance

5. Daily transportation of equipment and fabric to working face

9. CONCLUSIONS/RECOMMENDATIONS

Our research confirms the need for concern about daily cover operations at sanitary landfills. Existing landfills are too valuable of a resource to neglect opportunities to extend their life. To avoid closing a landfill with volume remaining, we suggest looking at other techniques, such as geotextiles. Where geotextiles are not the best solution, we advocate a strong look at the productivity of the equipment operations, the landfill design, and the routing patterns of the earth-moving equipment.

Beyond these general normative conclusions, we present the following important results and recommendations for the landfill decision-maker's consideration:

1. Time-lapse analysis is a useful technique for studying the daily cover operations at landfills. Our analyses proved the great variability in productivity between different sites. Stop-watch studies could also be used for estimating cycle times.

2. Productivity varies substantially between landfills. Before investing in additional equipment, or upgrading existing equipment, landfill operators should look at their total requirement for daily cover, and estimate costs of different equipment combinations.

If they are available, we suggest using actual cost data from equipment and maintenance records, or actual rental figures. If not, we suggest using the Caterpillar Performance

Handbook and the "average conditions" rate, times 1.15, and adding labor at the local rate. In the absence of a study to determine equipment idle time, we recommend using a 20% idle time for each piece of equipment. Finally, we recommend using the methodology presented in Section 6.E to figure total costs for conventional landfill daily cover.

3. An effort was made with the aid of Lotus 123 plots to determine relationships between haul distance, landfill life, costs, and other variables. No definite relationships were found, apparently because of too many independent variables affecting haul distance--including landfill design, site conditions, and site management, planning, and organization. No one factor yielded a consistent relationship with haul distance, and hence we have not been able to determine clear relationships or break-even points with costs for a broad number of landfills. It is too site-dependent; however, each site should be able to determine such break-even points with specific equipment mixes and site conditions.

4. The use of draglines indicates impressive productivity results; they should be considered when choosing an equipment mix.

5. Direct dumping by scrapers eliminates double handling of the cover soil and is a superior technique to side dumping.

6. Two separate examples studied the cost of geotextile fabrics and conventional operations. The soil example

resulted in a cost of $0.42/SY installed; the fabric was somewhat more at $0.636/SY installed. Even though the examples were not exactly the same (the working face was slightly larger in the fabric example), this method obviously deserves consideration.

Since these figures represent only two, strictly hypothetical, average sites, the meaning of these figures should **not** be extended to a specific decision without a more detailed study for the site. Site characteristics and cover availability will determine which method will be the most economical. Switching to fabric will not entirely eliminate the need for earthmoving equipment, but it could drastically reduce the fleet or capacities needed.

7. The cost analysis of fabric did not consider the cost of the sewing machine and portable generator, but these are minor equipment costs relative to large earthmoving equipment. It also did not consider the positive value of volume saved in the landfill relative to six inches of soil, and did not value the ability to cover even when soil is too wet to use as cover. This type of life-cycle analysis is recommended for further research.

8. The following important results were obtained from the survey:

a. We received conflicting figures on the depth of daily cover actually achieved. Simple volume and area calculations yielded an average depth of 4.45 inches, and the direct

question yielded 5.80 inches. With the direct question, we recognize the difficulty in operators openly admitting violations of EPA regulations, and our observations also tend to support the former figure. It may even be less if actual measurements were made.

b. Because of wet soil, landfills in North Carolina do not cover refuse at all an average of 24 days per year.

c. Approximately 30% of all active labor time at landfills is spent on daily cover, averaging 42 man-hours per week for 61 landfills across North Carolina.

d. The average landfill operation has a total of 5.8 pieces of equipment, and uses an average of 2.7 pieces of equipment for daily cover.

e. The preceding points suggest that somewhere from one-third to one-half of the operating expenses of a landfill go to fulfilling the daily cover requirement.

f. Over 30% of the landfill operators responded that daily cover would limit the life their landfills, with an average of 3.5 years remaining life.

8. Geotextile fabrics can be easily installed as an alternate daily cover material, and could be used in wet conditions when soil isn't feasible. Operators should consider the use of fabric as an economic possibility, and use the methodology and figures described in Section 8 as an aid to their decision.

9. Follow-on research is needed to further quantify the life-cycle costs of fabric, the savings resulting from extended volume usage, and the value of being able to cover in wet conditions. All these will increase the value of fabric as a daily cover material relative to soil.

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Civil Engineering 562, Construction Productivity, Course Notes from Fall '86.

Phillips Fibers Corporation, numerous meetings, telecons, and discussions during the period from August 1987 to January 1988.

Rust, Dr. Richard R., Selected information from a report to Phillips Fibers Corporation, "Fabric Daily Cover Experiment, 23 October 1987 -- Catawba County."

Survey results from sixty-one landfills in North Carolina, Anonymity was promised.

Telephone interviews with heavy equipment rental agencies, December 21-22, 1987. The following agencies were contacted:

In Raleigh, NC, Area Code 919:

Pool Construction Equip., Inc.	821-3952
Gregory Poole Equipment Co. (Cat) Steve Boecking	828-0641
R.W. Moore Equipment Co. (John Deere) Bill Moore	772-2121
Dresser Equipment (IH) North Carolina Equipment Co.	833-4811
J.W. Burress, Inc.	781-9454
Case Power and Equipment Co.	851-1450
Hertz Equipment Rental Co.	834-2527

In Greensboro, NC:

Rimtrax Corporation (John Deere)	1-800-632-0376
E.F. Craven Co. Jim Adams	1-800-854-3499

In Charlotte, NC, Area Code 704:

Carolina Tractor and Equipment Co. (Cat)	596-8790

APPENDIX A

LANDFILL SURVEY AND COVER LETTER

«data a:misc.doc»

November 3, 1987

«gender» «first» «mi» «last»
«title»
«street»
«city», «state» «zipc»

Dear «gender» «last»:

The Civil Engineering Department at North Carolina State University is conducting research that may be very useful to your landfill operations. We are examining the application of soil daily cover to explore ways of improving efficiency and lowering costs. Improvements might be through better equipment combinations, better design of the excavation/covering process, different cover material options, or other variables that significantly affect the cost.

We need your help in gathering information about landfills in North Carolina. We are conducting detailed studies of selected sites near Raleigh, but time and resources prevent us from visiting as many sites as we would like. By filling out this questionnaire, you will inform us of your particular operation and our analysis will be more complete with your input. Also, your response might include an innovative technique or unusual situation that would suggest a better method for other supervisors.

Your response is not mandatory, but we would appreciate your answer to as many questions as your time permits. The Solid and Hazardous Waste Management Branch of the North Carolina Department of Human Resources recognizes the importance of our research and supports this survey (see their attached endorsement). Please give honest estimates of your operations and any problems you face at your site. Your answers will be kept confidential--they are for research purposes only. Please fill out a separate survey for each of the landfills you supervise.

We would like the surveys returned by December 9th, because we hope to finish our analysis by December 20th. In case you have any questions about the survey or what we are trying to accomplish, please call my research assistants: Greg Emanuel or

Fuad Arbid at (919) 737-7194; or me, Dr. Richard Rust at (919) 737-2331. If you don't feel you are the appropriate person or agency to answer the survey, **please** forward it to the appropriate person. Thank you!

Sincerely,

Dr. Richard R. Rust
Asst. Professor of
Civil Engineering

Please answer the following questions as completely as time and available data permit. Include comments, estimates, and explanations in the spaces provided after each question. We are concentrating our efforts on the cost effectiveness of daily cover and to do this, we need accurate data on current operations--including equipment time, maintenance costs, and manhours. Please give accurate estimates no matter how poor production rates may sound. If you only give your best performance rates in best weather with no equipment downtime, it will not help our study. We will be the only ones to see your data. Only data on consolidated averages will be released in our report. We will not reveal your production rates to anyone else so please be as honest and accurate as possible. Thank you for your support!

1. How would you describe the design of your landfill?

____ Area Method
____ Trench Method
____ Combination of methods

Other specifics, such as being in the mounding stage, site bisected by public road, very hilly site, high water table, size of cells, or any other useful description that will help us understand the uniqueness of your site layout and design, and why. We would appreciate a sketch to help us visualize and understand your operation. Please attach a small sketch of the overall layout (or copy of a site plan) and a sketch or profile of the active operating area.

2. Do you currently use or are you moving toward non-conventional technologies in your landfilll operation, i.e incineration, sorting, baling, shredding, etc? When?

3. What is your current average daily tonnage that you are handling? (If tonnage estimates can not be made, use the space provided below to estimate daily volume.)

Our current daily/weekly/monthly/annual (circle one) tonnage is ______________________tons/______. We do/ do not have scales, therefore this is/is not an estimate.

4. At what rate is your tonnage (or volume) increasing? Attach tonnage data from past 5-10 years, if readily available.

Our current demand is growing/declining at a rate of _____%.

5. What is the projected life of your landfill, based on its volume-holding capacity?

The current projected volume-life of the landfill is _______.

6. Do you survey the landfill site periodically to keep track of volume use? How often?

_____ No, we do not conduct periodic volume surveys
_____ Yes, we conduct volume surveys about once every ________________ (time period)

7. Do you foresee permitting or regulatory problems forcing the closure of your landfill? When?

8. Roughly, what is the size of the average working face, that is, the amount that must be covered at the end of each day; and what is the size of the "active" landfill site, those areas still available for additional filling or mounding?

The average size of the working face is ______' X ______'
Our active landfill site covers _________ acres

9. What is your estimate of the volume of soil that is moved daily to cover the working face?

We move approximately _____ cubic yards of cover soil daily

10. What is the actual thickness of soil daily cover that you achieve, on the average? NOTE: No one expects that six inches of soil will always cover the garbage. On the average, it may be more or much less, and it will of course depend on how rough the garbage surface is. In any instance, this question is not intended for any other purposes than research information. Answers will be kept anonymous and confidential!

The average thickness of soil cover achieved is _____ "

11. Is your cover soil a suitable cover always, or do you have problems with clayey soils when it gets wet, or rocks? Explain:

12. The life of some landfills is limited by the amount of daily soil cover material readily and economically available. Are you in this situation, or do you anticipate being in that situation ever at your site?

_____ Yes, daily cover material will determine the life
_____ We anticipate d ily cover material becoming a problem in the year ______
_____ No, cover material is readily available, and will not affect the life of our site

13. What is the average haul distance from where your soil cover is excavated to where it is placed on the working face? Estimate if necessary.

Our average haul distance is _________________________

14. Is the excavation for cover material off-site, or do you purchase borrow material from elsewhere?

15. From our recent observations of landfill operations, we have noticed that rains and mud can totally prevent the trash from receiving any daily cover, unless an excess of soil happens to be stockpiled nearby. How many days per year would you estimate that bad weather prevents the trash from being covered?.

Because of bad weather, the trash is not covered ____ days/yr

16. Please list your current equipment fleet by checking the appropriate spaces below:

Equipment	Quantity	Model/Capacity	Age (yrs)
Trashmasters			
Dozers			
Front End Loaders			
Scrapers			
Elevating			
Regular			
Other (i.e. Draglines)			

17. Do you anticipate any changes in your equipment mix, or are you trying to upgrade or change it?

Explain:

18. The application of soil daily cover often involves several pieces of equipment. The same pieces of equipment are also used for construction and maintenance of haul roads, sedimentation ponds, and drainage ditches. Considering all the activities of a piece of equipment, estimate the total time and percentage of time specific pieces of equipment are used for moving daily cover relative to all other tasks. For example, if an elevating scraper in a typical week spends 20 hours per week excavating, moving, and placing daily cover; and 5 hrs/week doing other tasks--then 80% of its productive time would be dedicated to daily cover.

NOTE: This is a difficult question to answer accurately, so simply make your best educated guess--based on your experiences and opinions of equipment operators and supervisors. Obviously, a rainy spell might require more than average time spent on road maintenance. We're concerned with average times over the course of a year.

Equipment	Hrs/week spent on Daily Cover Operations	% of Total Productive Time

19. Most equipment operators perform different tasks on different pieces of equipment throughout the day. Do you have operators that are dedicated to only one piece of equipment, or do they run various pieces, depending on what is needed at the time? Briefly explain your operator/equipment arrangement, including crew size:

20. Considering your response to the previous question, estimate (based on your experiences of the past year) the average number of man-hours/week spent in fulfilling the requirement for soil daily cover. Consider poor production periods as well as smooth operating procedures. Include the portion of supervisors time spent in this area.

Total man-hours per week spent on daily cover: ___________

Total man-hours per week spent for all activities at the landfill: ______ (Do not include office and scale personnel, but include supervisory time on the site).

21. Part of our research involves getting an idea of the cost per square yard of applied soil daily cover. To arrive at this figure for different sites requires information on equipment operation and maintenance costs, and personnel costs. Is this type of information readily available in your office (or elsewhere) and would you be willing to share this information for research purposes if we visited your operation? (Check all that apply)

_____ Yes, the following information is readily available:
Equipment Operation/Maintenance _____
Equipment Initial Cost/Depreciation _____
Equipment operator (personnel) costs _____

______ No, this information is not readily available

______ Yes, we would be willing to help you find this information for your research

______ No, we don't have the ability or time to help you find this information for your research

22. Do you have information on the purchase, permitting, and start-up costs of your current or recent landfill sites, or can you suggest where such information might be available? Do you have any cost estimates for future sites?

____ Yes, we have cost information available for our landfill
____ Yes, we have recent estimates for a new landfill site

Explain: For example, "We feel our next landfill will require 1 year for site screening, selection, and acquistion; 1 year for site investigation and permitting; and 6 months for site development at a total cost of $4.8 million dollars.

____ No, cost information for our landfill is not available
____ No, we don't have the information, but suggest you try to get it from:

(Name or title, telephone number or address)

APPENDIX B

MEMO FROM NORTH CAROLINA DEPARTMENT OF HUMAN RESOURCES,

SOLID AND HAZARDOUS WASTE MANAGEMENT BRANCH

North Carolina Department of Human Resources
Division of Health Services
P.O. Box 2091 • Raleigh, North Carolina 27602-2091

James G. Martin, Governor
David T. Flaherty, Secretary

Ronald H. Levine, M.D., M.P.H.
State Health Director

September 24, 1987

MEMORANDUM

TO: Dr. Richard R. Rust
N. C. State University
Civil Engineering Department

FROM: William L. Meyer, Head WLM
Solid & Hazardous Waste Management Branch
Environmental Health Section

SUBJECT: N. C. State University Survey
Economics of Soil Daily Cover

Our office encourages each owner/operator to participate in the survey. Knowledge gained which will enable landfills to operate more cost effectively is of critical importance to each of us.

TFD/WLM:ssj

APPENDIX C

COUNTY MANAGER LETTER

<data countmgr>

28 October 1987

<title>
<address>
<city>, NC <zip>

Dear <name>:

Sanitary landfills are a diminishing and valuable resource. The Civil Engineering Department of North Carolina State University is researching ways to improve sanitary landfill operations and to extend the lives of our existing landfills. The Solid Waste Management Branch of the North Carolina Department of Human Resources anticipates a critical shortage of landfill space and therefore endorses our research.

We have sent questionnaires to your landfill supervisors. The success of our research depends upon the timely completion and return of these surveys. Therefore, we would appreciate your support in encouraging your landfill supervisors to complete and return the forms as soon as possible. If you have any questions please feel free to contact me at North Carolina State University (919) 737-7194 or 737-7207. Thank you.

Sincerely,

Dr. Richard R. Rust
Asst. Professor of
Civil Engineering

APPENDIX D

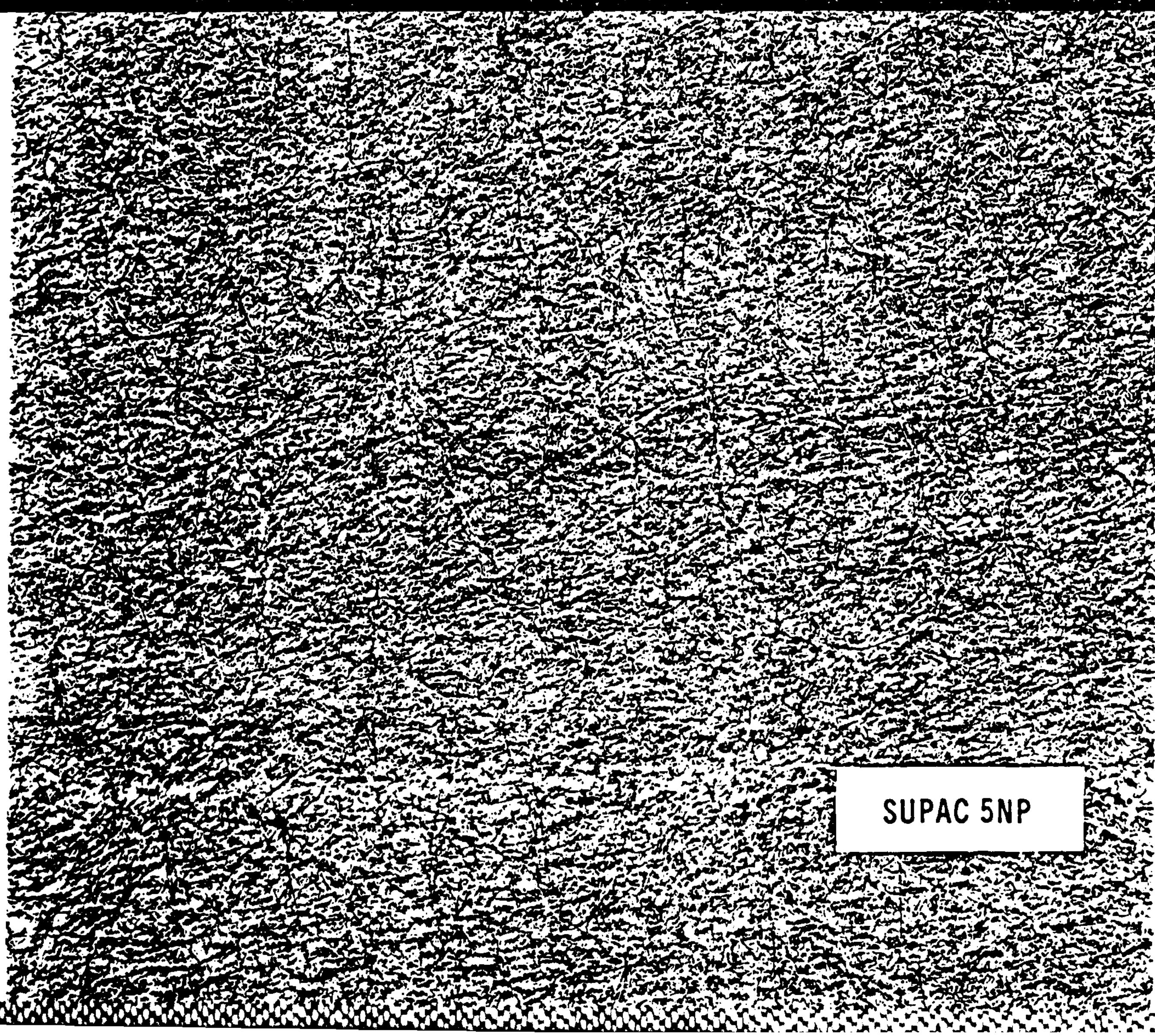
FABRIC SAMPLE

Geotextile

PHILLIPS 66

ENGINEERED GEOTEXTILES

SUPAC®



APPENDIX E

DBASE III+ SURVEY DATA STRUCTURE

Structure for database : C:sanit.dbf
Number of data records : 61
Date of last update : 01/09/88

Field	Field name	Type	Width	Dec
1	PERMIT_NO1	Numeric	2	
2	PERMIT_NO2	Numeric	2	
3	LF_NAME	Character	40	
4	TITLE	Character	30	
5	GENDER	Character	4	
6	FIRST	Character	10	
7	MI	Character	2	
8	LAST	Character	15	
9	COMPANY	Character	30	
10	STREET	Character	25	
11	CITY	Character	20	
12	STATE	Character	2	
13	ZIP	Numeric	5	
14	ZIPC	Character	5	
15	TELE_AC	Numeric	3	
16	TELE_NO123	Numeric	3	
17	TELE_NO5_8	Numeric	4	
18	RETURNED	Character	1	
19	OPEN	Character	1	
20	STATUS	Memo	10	
21	LF_TYPE	Character	1	
22	Q1	Character	1	
23	Q1NOTES	Memo	10	
24	Q2	Character	1	
25	Q2TECH	Character	5	
26	Q3PERIOD	Character	1	
27	Q3TONS	Numeric	7	
28	Q3SCALES	Character	1	
29	Q3ESTIMATE	Character	1	
30	Q4RATE	Numeric	5	1
31	Q5LIFE	Numeric	4	
32	Q6VOLSURVY	Character	1	
33	Q6PERIOD	Numeric	2	
34	Q7CLOSURE	Character	1	
35	Q7DATE	Numeric	4	
36	Q8DIMEN1	Numeric	3	
37	Q8DIMEN2	Numeric	3	
38	Q8LF_ACRES	Numeric	5	1
39	Q9SOIL_VOL	Numeric	4	
40	Q10THICKNS	Numeric	4	1
41	Q11SUITABL	Character	1	

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Structure for database : C:sanit.dbf
Number of data records : 61
Date of last update : 01/09/88

Field	Field name	Type	Width	Dec
42	Q11SOILPRO	Character	14	
43	Q12SOILIMT	Character	1	
44	Q12SOILIFE	Numeric	4	
45	Q13HAULDIS	Numeric	5	
46	Q14DCSOURC	Character	2	
47	Q14BOROCOS	Numeric	5	2
48	Q15RAINDAY	Numeric	3	
49	TRASH1MODL	Character	20	
50	TRASH1AGE	Numeric	2	
51	TRASH2MODL	Character	20	
52	TRASH2AGE	Numeric	2	
53	TRASH3MODL	Character	20	
54	TRASH3AGE	Numeric	2	
55	DOZ1MODEL	Character	15	
56	DOZ1AGE	Numeric	2	
57	DOZ2MODEL	Character	15	
58	DOZ2AGE	Numeric	2	
59	FEL1MODEL	Character	20	
60	FEL1AGE	Numeric	2	
61	FEL2MODEL	Character	20	
62	FEL2AGE	Numeric	2	
63	FEL3MODEL	Character	20	
64	FEL3AGE	Numeric	2	
65	SCRAP1MODL	Character	15	
66	SCRAP1TYPE	Character	1	
67	SCRAP1CAP	Numeric	2	
68	SCRAP1AGE	Numeric	2	
69	SCRAP2MODL	Character	15	
70	SCRAP2TYPE	Character	1	
71	SCRAP2CAP	Numeric	2	
72	SCRAP2AGE	Numeric	2	
73	SCRAP3MODL	Character	15	
74	SCRAP3TYPE	Character	1	
75	SCRAP3CAP	Numeric	2	
76	SCRAP3AGE	Numeric	2	
77	OTHER1NAME	Character	20	
78	OTHER1MODL	Character	15	
79	OTHER1CAP	Numeric	4	2
80	OTHER1AGE	Numeric	2	
81	OTHER2NAME	Character	20	
82	OTHER2MODL	Character	15	

APPENDIX E

DBASE III+ SURVEY DATA STRUCTURE

Structure for database : C:sanit.dbf
Number of data records : 61
Date of last update : 01/09/88

Field	Field name	Type	Width	Dec
83	OTHER2CAP	Numeric	4	2
84	OTHER2AGE	Numeric	2	
85	OTHER3NAME	Character	20	
86	OTHER3MODL	Character	15	
87	OTHER3CAP	Numeric	2	
88	OTHER3AGE	Numeric	2	
89	OTHER4NAME	Character	20	
90	OTHER4MODL	Character	15	
91	OTHER4CAP	Numeric	2	
92	OTHER4AGE	Numeric	2	
93	EQUIPTOTAL	Numeric	2	
94	Q17EQUIPCH	Character	1	
95	Q17CHANGE	Memo	10	
96	DC1	Character	2	
97	DC1HRS	Numeric	2	
98	DC1PCT	Numeric	3	
99	DC2	Character	2	
100	DC2HRS	Numeric	2	
101	DC2PCT	Numeric	3	
102	DC3	Character	2	
103	DC3HRS	Numeric	2	
104	DC3PCT	Numeric	3	
105	DC4	Character	2	
106	DC4HRS	Numeric	2	
107	DC4PCT	Numeric	3	
108	DC5	Character	2	
109	DC5HRS	Numeric	2	
110	DC5PCT	Numeric	3	
111	Q19OP_EQ	Character	1	
112	Q19CREWSIZ	Numeric	2	
113	Q19CREWMEM	Memo	10	
114	Q20DCMH_WK	Numeric	3	
115	Q20LFMH_WK	Numeric	3	
116	Q21INFOAVL	Character	5	
117	Q21REDYAVL	Character	8	
118	Q22LFCOST	Character	5	
119	Q22NLFMEMO	Memo	10	
120	Q22NLFCOST	Numeric	7	2
121	Q22NLFTIME	Numeric	2	
122	Q22TGADRS	Character	50	
123	ADDL_COMMT	Memo	10	
** Total **			864	